AD-A264 825

...MENTATION PAGE

Form Approved
OMB No. 0704-0188

...verage 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and ...of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including ..., Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, ...ct (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	March 1993	Professional Paper

4. TITLE AND SUBTITLE

LASER BASED 3D VOLUMETRIC DISPLAY SYSTEM

5. FUNDING NUMBERS

PR: CD13
PE: N/A
WU: DN303151

6. AUTHOR(S)

P. Soltan, J. Trias, W. Robinson, W. Dahlke

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Command, Control and Ocean Surveillance Center (NCCOSC)
RDT&E Division
San Diego, CA 92152–5001

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Naval Command, Control and Ocean Surveillance Center (NCCOSC)
RDT&E Division
San Diego, CA 92152–5001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

DTIC
ELECTE
MAY 2 4 1993
S A D

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

DTIC
ELECTE
MAY 2 4 1993
S A D

13. ABSTRACT (*Maximum 200 words*)

In the past several years, the Display Systems Branch, Naval Ocean Systems Center (NOSC), has been involved in the development of laser based display systems with the goal of upgrading the image quality of shipboard displays. In this paper we report work on: (1) developing laser generated 3D volumetric images on a rotating double helix, (where the 3D displays are computer controlled for group viewing with the naked eye), and (2) system feasibility results along with the first and second generation component parameters.

93-11428

Published in *SPIE/IS&T's Symposium on Electronic Imaging Science and Technology*, Feb 1992, p 138.

14. SUBJECT TERMS			15. NUMBER OF PAGES
multi planer displays volumetric displays	virtual images airtraffic control	medical imaging	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAME AS REPORT

21a. NAME OF RESPONSIBLE INDIVIDUAL	21b. TELEPHONE (Include Area Code)	21c. OFFICE SYMBOL
P. Soltan	(619) 553-3584	Code 414

Accesion For	
NTIS CRA&I	☑
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution /	
Availability Codes	
Dist	Avail and / or Special
A-1	

SPIE—The International Society for Optical Engineering

February 9-14, 1992
The San Jose Convention Center
San Jose, California

LASER BASED 3D VOLUMETRIC DISPLAY SYSTEM

Parviz Soltan, John Trias, Waldo Robinson, Weldon Dahlke
Display Systems Branch
Naval Ocean Systems Center
San Diego, California, USA

ABSTRACT

In the past several years, the Display Systems Branch, Naval Ocean Systems Center (NOSC), has been involved in the development of laser based display systems with the goal of upgrading the image quality of shipboard displays. In this paper we report work on: (1) developing laser generated 3D volumetric images on a rotating double helix, (where the 3D displays are computer controlled for group viewing with the naked eye), and (2) system feasibility results along with the first and second generation component parameters.

1.0 INTRODUCTION

NOSC is developing a device for display of data, information, and scenes in a three-dimensional-volume. It incorporates a 13-inch diameter double helix that spins at approximately 10 revolutions per second, thereby filling a cylindrical volume. Under computer control, a laser beam is directed to illuminate discrete volume points (voxels) on the helix as required by the scene to be created. The laser light scatters from the surface of the helix, so that each voxel appears to the observer to emanate from a point that has x-y coordinates determined by the position of the laser beam, and a z-coordinate determined by the height of the helix at the illuminated point the moment it is illuminated. Any point within the cylindrical volume can be computer addressed with the appropriate synchronization of the laser beam, Acousto-Optic (AO) scanner, and the phase of the helix.

This 3D Volumetric Display System uses a laser beam which is directed at the appropriate point on the helix at the appropriate time by a commercial AO random scanner. Presently, because of various undesired system delays, (especially those delays due to the design limitations of the commercial AO scanners), only 4,200 voxels can be generated at a 20 hertz refresh rate.

1.1. Background

An ideal 3D volumetric display allows the volume to be viewed from any position by a number of observers with the naked eye. It provides an actual physical volume of images in real-time having height, depth and width.

The concept of laser generated 3D volumetric displays was suggested by Rudiger Hartwig of the University of Stuttgart in the early 1980s, by using a laser beam to illuminate the surface of a rotating helix. The system feasibility, however, was demonstrated by Don Williams of Texas Instruments (TI), at the 1988 SID International Symposium in Anaheim, CA. He showed a laser beam generating simple 3D geometric figures in a volume defined by a rotating disc.

During the 1980s another volumetric (multi-planar) technology, called "Space-Graph 3D Display System", was developed by Lawrence Sher of Bolt, Beranek & Newman (BBN). This CRT-based technology uses a vibrating flexible mirror to provide the 3rd dimension for reflected images off a CRT. A maximum volume of 25 by 25 by 25cm with a resolution of 24,000 points in each stroke, at a 30Hz refresh rate, can be generated.

A NOSC team, realizing the potential application of the laser generated 3D volumetric display in real-time, sought and received funding from the Navy and Air Force, (and recently DARPA), to begin further investigation and improvement of the laser based technology. In early 1990, NOSC decided on the following technical objectives:

1. Develop an advanced AO random scanner that could display more than 35,000 voxels with 256 by 256 "x" and "y" addressability per voxel in 1/20th of a second.

2. Develop an electronic control card for a 386 computer to be called a Volumetric Display Refresh Generator (VDRG), in order to make the 3D display refresh operation independent of the computer speed, processing power, and data processing needs.

3. Develop a double helix for the display media which would correct the mechanical imbalance and vibration of the single helix, proposed earlier by Hartwig, and also lower the noise at the required rotational speed. NOSC shall also continue the search for a non-moving display medium technology, solid state or gas, to ultimately replace the helix.

4. Use multiple laser sources and scanners to provide full color 3D images.

5. Develop or procure appropriate computer software to direct the laser beam(s) in order to generate mono/color 3D images in real-time, for group viewing with the naked eye.

6. Show practical military, medical, and commercial 3D applications.

1.2 Overall System Description

The major components of the NOSC two-color (red and green) 3D Volumetric Display System are schematically illustrated in Figure 1. They are the Argon/Krypton white laser, dispersing prism, masking shutters, mirrors and lenses for color separation and beam collimation. Also, two AO random scanners, beam projection optics, a 13-inch diameter double helix, a computer with its electronic control cards, and associated software.

An external prism separates the multi-color white laser output beam into 647nm red and 515nm green beams. This Liconix Argon/Krypton Laser is an off-the-shelf laser that is capable of producing three color primaries (red, green, and blue), with greater than 100-milliwatt each, CW, from a single laser system.

The dispersion prism is followed by a group of mirrors, masking shutters and lenses which direct the beams into their respective single color AO scanners. The independent red and green laser beams are then projected onto the separate quadrants of the rotating helical display surface.

The display surface is a rotating 13-inch diameter double helix with a 6-inch depth that is simultaneously written on by one or more laser beams. Each laser beam is deflected in "x" and "y", using the property of Bragg diffraction in AO crystals. An AO modulator (not shown), inserted in the lasers optical beam path provides a means for the computer to control the intensity of the image on a voxel-by-voxel basis.

Two magnetic sensor switches mounted on the double helix shaft generate pulses at "0" and "180" degrees. The pulses are used to initialize the memory readout at the beginning of the image. The two-dimensional "x" and "y" coordinates of an image point are transformed into three-dimensional points, when the laser beam strikes the moving surface of the helix.

The computer system currently used is a Unisys Desk Top III. It has an Intel 80386DX Control Processing Unit (CPU) with an Intel 80387 Floating Point Unit (FPU), running at 20-megahertz. The Random Access Memory (RAM) has 20-megabytes. The system also has a 100-megabyte hard drive disk and VGA graphics.

The basic software consists of MS-DOS 4.01 and Zortec C++ Version 3.0. Under separate Navy software contracts, ETA Technologies (San Diego, CA) and BBN have developed software for the 3D Display System. ETA Technologies has developed at NOSC a program called "LASER", which controls the AO deflection of each voxel in the displayed image. BBN has developed the program "Laser Helix" which converts their spacegraph 3D Picture List files to "Laser Helix" files, that are displayable by the LASER program on the Double Helix 3D Display System.

Some of the three-dimensional images that have been provided by BBN include The Space Shuttle (Fig. 2), a geodome, earthquake fococenters, 3D molecular structure, half a Volkswagen body, a vectorcardiogram, and assorted maps. All this software demonstrates the feasibility of this 3D technology and clearly show the software development effort for enhancing the Air Traffic Control, Anti-Submarine Warfare (Fig. 3), coronary arteriogram, and animation techniques for image rotation that are in progress.

The following sections describe the basic design parameters and specifications of the major components and the performance of the NOSC 3D Volumetric Display System.

2.0 LASER SCANNING SYSTEM

Acousto-optic scanners based on BRAGG diffraction technology are used in the 3D Display System. Such a device is shown in Fig. 4. When laser light enters an AO device, the interaction of sound waves and light in a transparent medium will produce a periodic change in the refractive index of the material that can be utilized to deflect light. An Acousto-Optic Beam Deflector or (AOBD) is essentially an acoustically-driven grating that has no moving parts. It consists of an ultrasonic pressure transducer attached to a transparent crystal such as tellurium dioxide. The transducer is driven by an RF electrical signal and generates an acoustic wave that propagates along the length of the crystal. The acoustic wave causes variations in density, and thus the periodic refractive index of the crystal.

With appropriate designs, the first order diffracted beam has the highest efficiency. Its angular position is linearly proportional to the acoustic frequency, so that the higher the frequency, the larger the diffracted angle.

$$\Delta\theta=\lambda(\Delta f/v_a), \quad \Delta\theta = \text{diffraction angle}$$

where, λ = optical wavelength

v_a = acoustic velocity

Δf = frequency bandwidth

The resolution of an AO deflector is determined by the acoustic transit time τ and the total scanning bandwidth Δf. Light deflection by ultrasound is based upon the linear relationship between the acoustic frequency and the sine of the BRAGG angle, α. To obtain this relationship, substitute the quotient of sound velocity, ν, and sound frequency, f, for the sound wavelength, Λ, in the BRAGG diffraction equation:

$$\Lambda = v/f \quad 2 \sin \alpha = \lambda/\Lambda \quad 2 \sin \alpha = f\lambda/v$$

Substituting 2α for $2 \sin \alpha$ since Bragg angles are usually small. Now, 2α represents the angle by which the diffracted beam departs from the path of the incident beam, we vary f:

$$\Delta(2\alpha) = \Delta f \ \lambda/\nu$$

Light deflection is useful for television projection devices. What counts most in a light deflection device is not the deflection angle obtained (this is easily modified optically) but the number of angular positions, usually called the number of resolvable spots, that can be clearly distinguished from each other. This number is not changed by magnification.

To determine the number of resolvable spots, N, we divide the angular displacement $\Delta(2\alpha)$ by the laser beam diffraction spread $a_{min} = \lambda/D$ of a light beam projected from an aperture D. This spread determines how small a spot we can make. Resulting in the relationship:

$$N = \frac{\Delta(2\alpha)}{a_{min}} = \frac{\Delta f(\frac{\lambda}{v})}{\frac{\lambda}{D}} = \frac{\Delta f D}{v} = \Delta f \tau$$

Existing acousto-optic laser raster scanning systems are not suitable for the 3D displays that use a rotating Helix for the viewing screen. They are too slow and require a full "picture frame time" just to display a few points. On the other hand, a fully developed AO random laser scanner with adequate bandwidth and efficiency for flicker-free 3D display experiments, does not exist. Several off-the-shelf random access scanners were procured in order to prove system feasibility and establish our first generation AO random scanner specifications.

2.1 First Generation (AO) Random Laser Scanner

This scanner consists of a pair of (AO) beam deflectors and all necessary optics packaged into a small housing 8-inches square by 4-inches high. It is a complete random laser scanner with two linear VCOs and power amplifiers to drive the AO beam deflectors and an interface card to permit operation from a PC computer.

The performance specifications of this scanner are the following: (1) the spectral transmission range is 440nm to 830nm, (2) the number of resolvable spots is 256 by 256, (3) the deflection angle is from 6 to 10 degrees, (4) the throughput efficiency is 15%, (5) the AO processing time is 10-microseconds and the spot random access time is 13-microseconds maximum.

The AO processing time of this first generation scanner limits the amount of information that can be displayed; that is, the rate at which individual laser points that can be addressed. This AO scanner being used addresses approximately 4,000 volume elements or voxels per field at a 20Hz refresh rate, although the computer hardware and software that drives the display is potentially capable of providing data at rates one or two order of magnitude faster. Therefore, the next step is to overcome these limitations to increase the number of voxels available for display.

2.2 Second Generation AO Random Scanner

A new scanner has been designed and is being assembled with off-the-shelf component parts. The modulation system will have four AO modulators and drivers that will accept a 1mm diameter polarized beam. The scanner section is composed of four XY AO-beam-deflectors. It is a multi-beam AO scanning system that is analogous to digital parallel processing. The parallel data rate is equivalent to a serial data rate of 1.25-microseconds per spot. This system scans four spots in 5-microseconds or 1/1.25-microsecond to produce voxel rate of 800,000 per second. If the

frame time is 50-milliseconds or 20Hz, there will be 40,000 voxels per field; thus, one order of magnitude improvement in the number of voxels per field with an x, y spot resolution of 256 by 256.

3.0 DEVELOPMENT OF ELECTRONIC CONTROL CARDS

3.1 First Generation Control Cards

The Volumetric #1 Interface Card is a printed circuit board designed to accurately control the position of a single laser beam on the 3D display. The board has a component count of 329 items with a mixture of surface mount and discrete components.

A dual port Random Access Memory (RAM) provides two independent ports (A&B) with separate control, address and data buses that permit independent asynchronous access for writes and reads to any location in memory, shown in Fig. 5. This property allows the writing of data into Port A at the "Computer's" rate while simultaneously reading out an image at Port B at the refresh rate for the helix.

Dual port RAM is used to hold the data on the individual points of the image to be displayed. These 2-Dimensional Points are transformed to voxels (3-dimensional points), when the laser beam hits the moving surface of the helix. The points' position in the image list relative to the position of the helix surface at readout time determine the depth.

Equal time slices are allotted for each point or voxel in the 3D display image. The points in the image are sequentially read from Port B of the memory starting with the address held in counter "B".

Counter "B" is reloaded with the beginning value held in the Initial Register whenever the Helix shaft reaches 0 or 180 degrees. The address counter "B" always increments from this initial value. This arrangement allows different memory pages to be displayed by just changing the value in the Initial Register. Typically, the 3D Memory is configured as three 4K pages.

The Data "B" readout rate from memory is under computer software program control via the 82C54-2 programmable timer. It is currently programmed to periodically increment counter "B" address every 12.0-microseconds thus allowing up to 4,166 different voxels to be read and displayed in 1/20 of a second.

The image refresh rate has been nominally set at 20Hz. This is a compromise between displaying more image voxels per frame and image flicker.

The Shaft Motor Speed Control regulates the speed of the 3D displays shaft since the computer sends a 16-bit word to the motor register. where the lower 12-bits of it are converted by a 12-bit DAC to furnish a 0V to +9.6v control signal to the helix DC motor.

The shaft speed circuitry accurately determines the helix's actual shaft speed without an expensive shaft encoder and takes a minimum amount of the computer's time.

The computer can read the shaft register at any time and by multiplying this count by 4-microseconds (period of the 250 Khz shaft counter clock), one can determine the actual speed of the helix to within 4-microseconds. The shaft register is loaded with the shaft counters value when the helix's shaft reaches 0 degrees; thus, the shaft count is available to be read by the computer for one complete shaft revolution. The shaft register is cleared immediately after the computer has read the register contents.

3.2 Second Generation Control Cards

Volumetric Display Refresh Generator (VDRG) #2 board (the second generation control card) is currently being designed to include essentially all of VDRG #1 features plus the following major additions:

- The Dual Port Memory has been expanded from 12,288 24 bit words to a minimum of 35,000 32 bit words with 12 bits for X, 12 bits for Y, and 8-bits for intensity. We are attempting to expand to 65,536 36 bit memory words for a single image, or 2-pages of 32K words for animation.

- The unit will have a 8-bit Input Video Lookup Table for intensity and the intensity output will consist of 8-parallel TTL lines containing the digital intensity information as well as one analog intensity line (0 to + 1v).

- Other TTL outputs are the Memory "B" Register Clock, 12 bits of X, 12 bits of Y, and Index "A" Signals.

An order has been placed for a Hyperspeed D860-4108 board that has one 40MHz Intel i860 processor and 8-megabytes of RAM on board. This board will be used as a Floating Point Accelerator Card and has the capability of 80 million floating point instructions per second. This board should speed up the floating point operations by a factor of 4 to 16 times over the current Intel 387/20 FPU.

4.0 DEVELOPMENT OF THE IMAGE VOLUME

4.1 First Generation Helix

The first display surface assembled for demonstrating the 3D concept using acousto-optic deflected laser light was an elliptical-shaped disk of plastic mounted on the end of a motor shaft at a 45-degree angle via an adapter machined from aluminum. The size of the disk was 3-inches in the minor axis and 4.5-inches in the major axis.

The second type of display surface to be investigated was the single-surface helix that was proposed by Hartwig. This surface could improve the volume available for displaying data but had dynamic balance problems.

Fabrication of the 3rd type produced a balanced double helical surface made of aluminum, 13-inches in diameter and 6-inches in height with a solid center (about 1-inch in diameter).

We are able to display an image about 3-inches on each side and 6-inches deep. It is safe to spin at any speed required for developing the 3D technique. This new helix has been installed, and was fully utilized during all of 1991 3D experiments.

A 3-inch diameter by 2-inch long hub was machined as part of the helical surface to aid in the holding of the part during the machining processes. This hub subsequently proved to be an aid in adapting to motor shafts of different diameters and it provided a convenient place to mount two rotational angle synchronizing magnets 180-degrees apart that would sweep past a Hall-effect switch that actually generated the sync pulses for the Volumetric Display Refresh Generator.

4.2 Second Generation Helix

The display image volume defined by the rotating helix can theoretically be as large as the application requires and have as many laser sources as is needed to generate the necessary display elements in real-time. The display volume can be enlarged by simply increasing the diameter of the helix to meet the application requirements.

The second generation 3D surface development (See Fig. 7), will produce a double helical surface 35.2-inches in diameter (active) and 18-inches of height, thus producing a surface pitch of 36-inches. Other characteristics of the design include:

- A large helix with no central rotational shaft,
- Translucent display surface (for rear projection),
- 36-inches diameter,
- 18-inches height,
- Transparent top and bottom plates,
- Support/drive mechanism.

5.0 SUMMARY AND FUTURE DEVELOPMENT

5.1 Laser Scanner

The feasibility of a 3D volumetric display has been demonstrated. Using random access acousto-optic beam deflectors, computer images are displayed in three dimensions on a rotating helical surface. In its current configuration the amount of information displayed is limited by the rate at which individual laser points can be addressed by the acousto-optic deflectors. Only 4,200 voxels can be generated in 1/20th of a second.

We are currently developing a new scanner with off-the-shelf component parts. This device will scan four spots in 5-microseconds to produce 40,000 voxels per field, an order of magnitude improvement over the present scanner.

5.2 Software

Software programs, using prerecorded static images, have produced excellent results: 3D images of maps, the space shuttle, electrocardiogram and geodome have further demonstrated the feasibility of this 3D volumetric technique for group viewing with the naked eye. Next will be developed software enabling the display of 3D images in real-time with animation. We will employ programs enabling the use of radar, sonar, and medical information for Air Traffic Control, Anti-Submarine Warfare and medical applications in real-time.

5.3 Electronic Control Cards

In order to make the 3D Display Refresh Operation independent of the computer speed, an electronic control card has been designed. This 8-layered display interface card, (called VDRG or NOSC Volumetric #1 Board), is currently in full operation and is capable of addressing up to 12,288 volume points (voxels) on the surface of the spinning helix.

A dual port Random Access Memory (RAM) provides two independent ports (A&B) with separate control, address and data buses that permit independent asynchronous access for writes and reads to any location in memory. This property allows data to be written into Port A at the Computer's rate while simultaneously reading out an image at Port B at the desired helix's data refresh rate.

The design of the second generation control card (called NOSC Volumetric #2 Board), is underway. It is designed to address a minimum of 35,000 voxels/color on the surface of the new 36-inch diameter helix.

Multiple laser beams require additional volumetric cards (one per laser beam). Each card will add 35,000 to 65,000 voxels to the 3D display surface depending on the refresh rate.

5.4 The Helix

The display image volume defined by the rotating helix can theoretically be as large as the application requires and have as many laser sources as is needed to generate the necessary display elements in real-time. The display volume can be enlarged by simply increasing the diameter of the helix to meet the application requirements.

The design of a new 36-inch diameter helical surface with no central shaft is near completion. This is to provide color images and will be the viewing surface for a full color 3D display system that incorporates the improved AO scanners (red, blue and green), that can accommodate more than 35,000 voxels per acousto-optic scanner.

5.5 A New Non-Moving Image Volume

A new approach for volume visualization is being pursued. This approach is to develop a method of 3D volume imaging using a non-moving matrix. An initial method to be investigated will be imaging techniques within a solid state matrix. The 3D display works by exciting the voxels (volume pixels) with two laser beams that intersect at specified points inside a volume of transparent fluorescent material. Materials in the form of solids that will upconvert infrared laser light to visible light. The red, green, and blue spectral bands have been studied and demonstrated by other workers over the past two decades. Many of these materials have non-linear or stepwise excitation processes that suggest possible techniques for implementing a 3D visualization system. Work on this approach coupled with our scanning technique is being pursued.

6.0 ACKNOWLEDGEMENTS

The authors wish to express their appreciation to Mr. W.J. King of the Office of Naval Technology (ONT), to Mr. Richard Slavinski of Rome Air Development Center (RADC), to Drs. Marko Slusarczuk and Tice DeYoung of Defense Advanced Research Project Agency (DARPA) for their continued support and encouragement. We would also like to thank Mr. Thomas Hess of Naval Air Development Center (NADC) and Mr. Duane Gomez of NOSC for their technical and managerial support.

7.0 REFERENCES

1. "A Laser-based Three-Dimensional Display", U. Brinkmann, Laser and Applications, Vol. 2, No. 3, 1983.

2. "Space Graph 3D Display System", Genisco Computer Corporation, Product Literature, Costa Mesa, CA July 1983.

3. "A Real Time Autostereoscopic Multiplanar 3D Display System", Rodney Don Williams, Felix Garcia, Jr., Texas Instruments, Inc., Dallas, TX, SID 1988 Digest.

4. "Laser Based Display Technology Development at the Naval Ocean Systems Center (NOSC)", T.E. Phillips, J.A. Trias, M.E. Lasher, P.M. Poirier, W. Dahlke, W. Robinson; SPIE, Vol. 1454, Beam Deflection and Scanning Technologies (1991), pp. 290-298.

5. "Image Quality of Volumetric Displays, Emerging Technology and Needed Research", Rodney Don Williams and Daniel Dono Loo, Texas Instruments, Inc., Dallas, TX, SID 91 Digest.

6. "Stereoscopic and Volumetric 3D Displays", T.E. Phillips, Survey of Technology, NOSC Technical Report 946 of June 1984.

7. "Dynamic Transparent Pages in a Volumetric 3D/4D Display", S.E. Wixon, Electronic Imaging 86, Nov. 3-6 1986, Institute for Graphic Communication, Boston, MA.

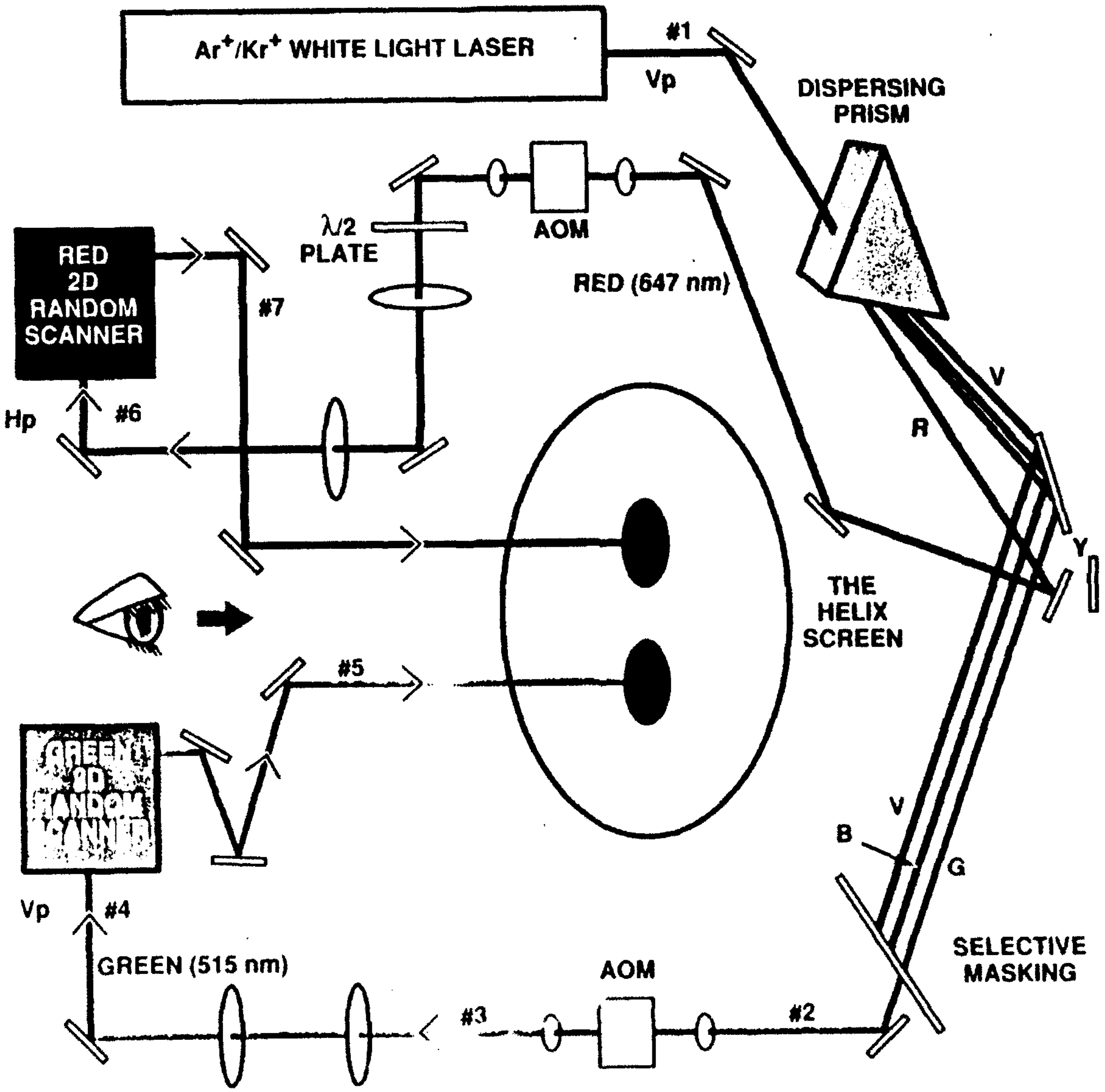
8. "Harnessing Virtual Space", Thomas A. Furness III, Armstrong Aerospace Medical Research Laboratory, SID 1988 Digest.

9. "A 3-D Display Using a Laser and a Moving Screen", H. Yamada, C. Masuda, K. Kubo, T. Ohira and K. Miyaji; Proceedings of the 6th International Display Research Conference, Tokyo, 1986.

10. "A 1075-Line Video Rate Laser Addressed Liquid Crystal Light Valve Projection Display", J. Trias, et al., Proceedings of the SID, pp. 275-277, Vol. 29/4, 1988.

NRaD — NAWC — DARPA — ROME LAB (AFSC)

Two-Color 3D Volumetric Display Schematic



B1126-1.41

FIG 2. Parviz Soltan, left, and Waldo Robinson observe a computer generated 3D image of the space shuttle. This laser generated 3D image can be group viewed in real time without filters or special glasses.

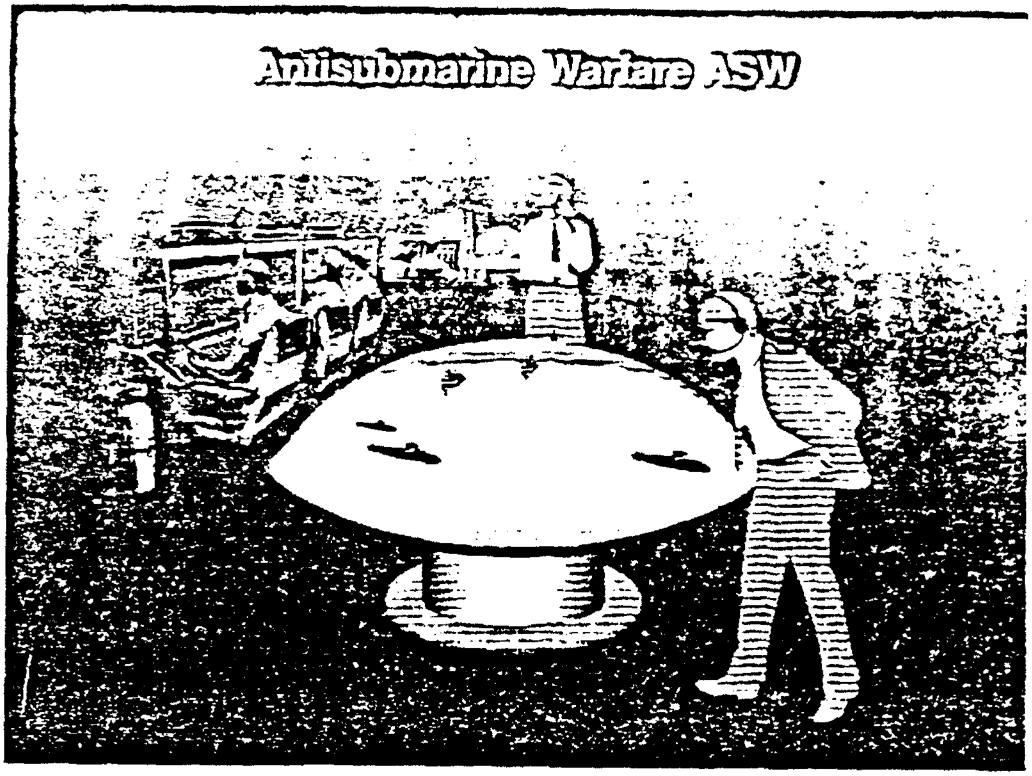


FIG 3. The volumetric display is a technique for presenting and communicating spatial awareness to the viewers in a submarine command center.

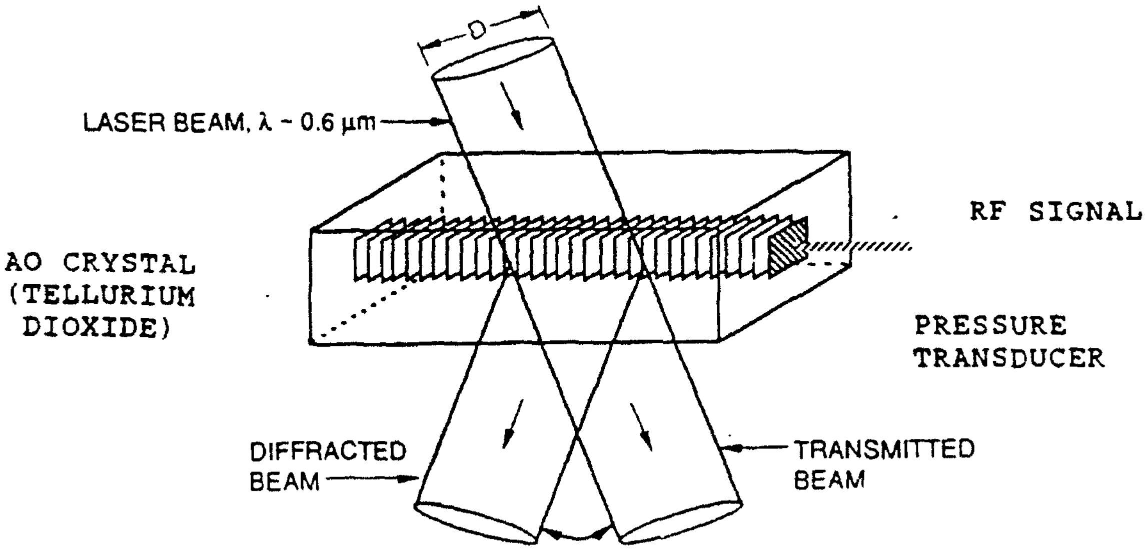


FIG 4. Bragg diffraction by an AOBD

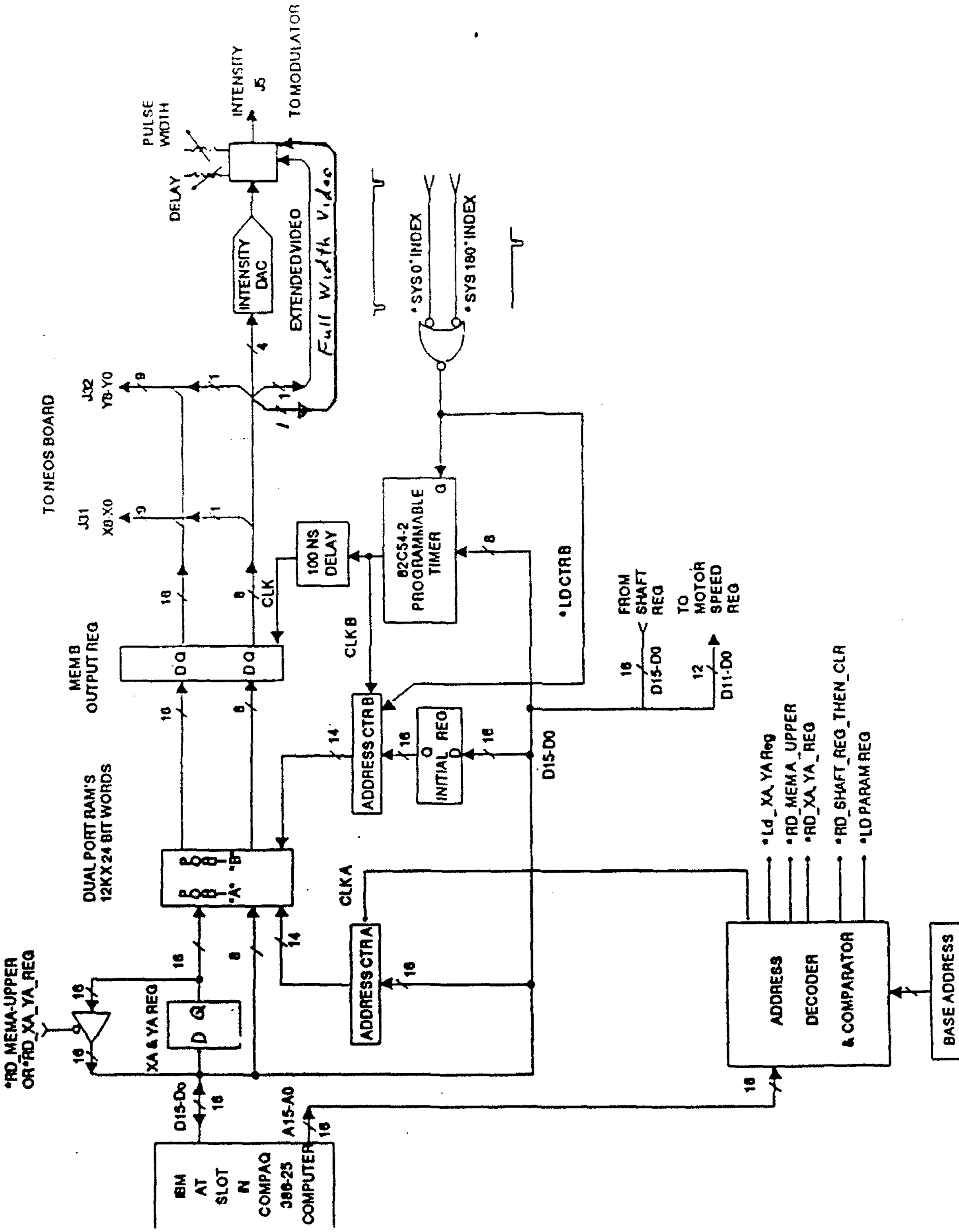


FIG 5. Simplified VOLUMETRIC #1

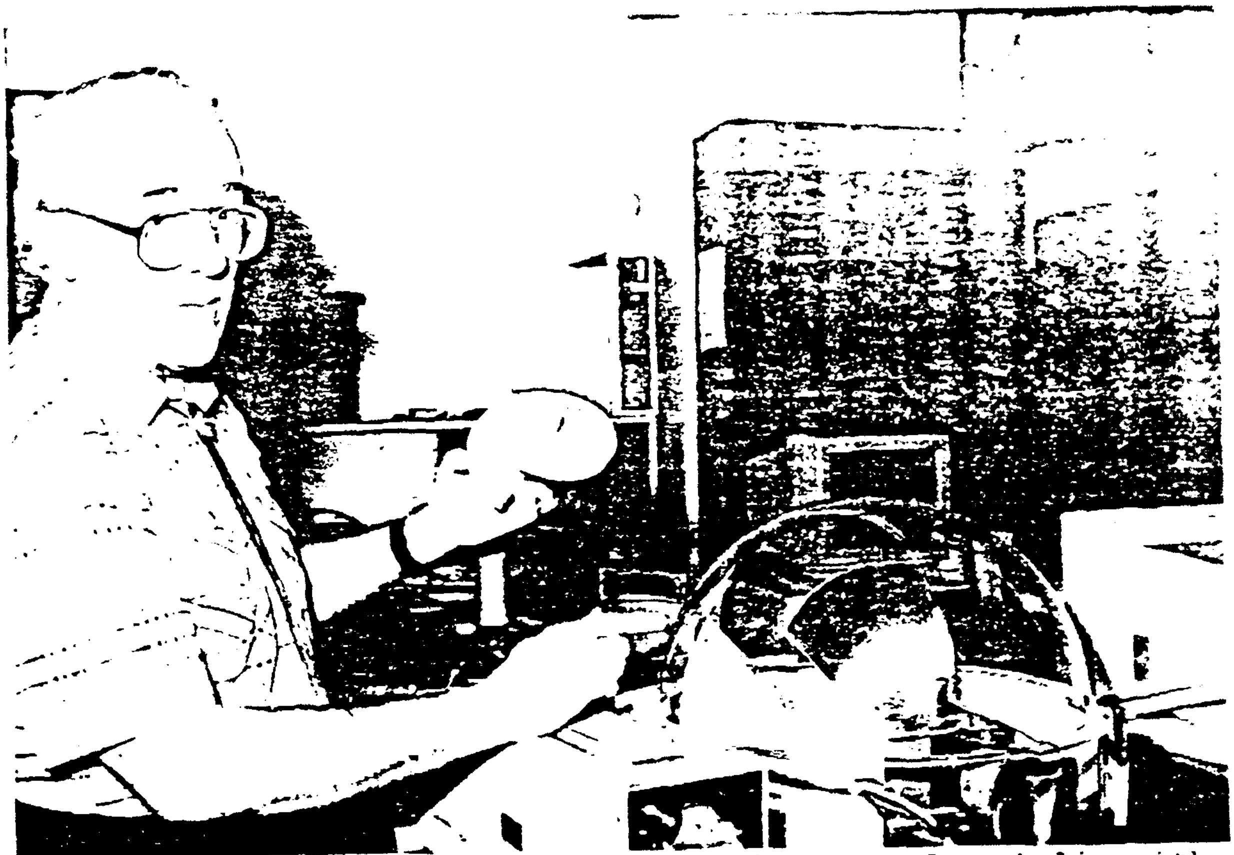


FIG 6. Waldo Robinson compares the single-surface helix with the 13" diameter double helix under the safety shield.

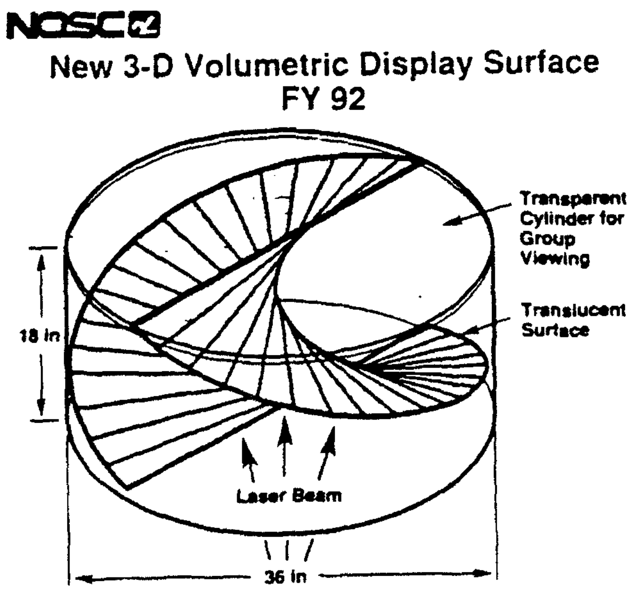


FIG 7. Second generation volumetric display surface